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A CASE STUDY ON WBV AND HAV IN AGRICULTURAL TRACTOR DRIVERS

Herbert Martins Gomes[1]
Tarciso Richter[2]
Universidade Federal do Rio Grande do Sul, Dep. Engenharia Mecânica, Av. Sarmento Leite, 425, sala 202, 2º. Andar, 90050-170 - Porto Alegre - RS - Brazil
[1] herbert@mecanica.ufrgs.br, [2] tarciso.richter@maxiforja.com.br

Abstract. *This work aims at assessing the exposed vibration levels in agricultural tractor drivers in usual working conditions on soybean crops in the southern Brazil. The evaluated work situations are (i) driving on unpaved terrain, (ii) driving on a paved road (asphalt) and (iii) driving in planting operation. The vibration measurement is evaluated using accelerometers in contact parts of the driver with the vehicle. A vibration meter is used to measure the vibration levels in the steering wheel (hand-arm vibration, HAV), and driver's seat, seat back and floor (whole body vibration, WBV). In addition, it is evaluated the daily exposure to vibration A(8) in usual working situations and it is compared to the daily exposure threshold set by standards. The lowest measured acceleration level in WBV was de 0,725 m/s² occurring in the seat back on asphalt. The higher acceleration level measured in HAV was 5,914 m/s² occurring at the same conditions. The study suggests checking the vibration levels also in other activities such as harvesting, since in the evaluated situations, the driver is exposed to harmful vibration.*

Keywords: *whole body vibration, hand arm vibration, vibration exposure in tractors.*

1. INTRODUCTION

Agricultural mechanization allowed the expansion of agriculture for large areas. Also the tractor use has significantly reduced the physical load with which the employees found themselves subjected, although they continue exposed to a certain physical and mental load, because the tractors have no suspension system, so the vibration levels are high in comparison with other road vehicles.

The current agricultural tractors in the Brazilian country, in your majority, have problems related to comfort and safety for the operators, since they are exposed to unhealthy levels above those permitted by the international working safety standards (Mathias, 1989).

Scholosser and Debiassi (2002) reported that the knowledge in ergonomics resulted in new concepts and they have caused manufacturers to begin to offer models of tractors with better comfort levels for location of controls and instruments. Mehta and Tewari (2000) described the various ways of analyzing the comfort of the tractor seat, both objective and subjectively. For objective analysis, several sensor types have been reported that assess body contact pressure of the operator with the seat, exposed to vibration frequencies. Thus, it was concluded that to perform a complete comfort study one should take into account specific biomechanics and ergonomic information like vibration levels, pressure distribution on the seat, operator posture and cushion material.

It is widely recognized that the agricultural tractor operators are exposed to high whole-body vibration levels (WBV) for normal farming operations as described in the literature. There is a growing need to develop research to understand how the vibration is transmitted to the human body and their influence on comfort, performance, health and safety of agricultural tractor operators. In this context, this paper focus basically on two objectives: (a) to determine the vibration levels in the seat, in the seat base, in the seat backrest and in the steering wheel (HAV) of an usual agricultural tractor for three regular working situations in soybean planting and (b) to assess the daily vibration exposure level in order to compare with the exposure limits defined by main international regulations.

1.1 Occupational Vibration

In 1934, the first studies on vibration suppression using suspensions started, aiming the vehicle comfort, although there was little interest in the human response to vibration (HSE, 2001). Real investigations of occupational vibration began seven decades after due to the increasing use of machines and the problems related to their use. Assessments were subjective, trying to estimate the threshold of human perception and equivalence with the response for each magnitude of vibration, in order to define limits that could be acceptable as uncomfortable for short and long periods of exposure.

In the 40s, the vibrations were identified as a potential health problem for both workers and people that used buses, trains and planes to travel. In 1949, it was found some problems in military vehicles drivers, who developed back pain resulting in retirement due to herniated disc problems (Piersol and Paez, 2010).

In 1960, Goldman published the first quantitative study of vibrations in the human body. Since then, several studies on occupational vibration were performed (Berasategui, 2000). Studies on threshold levels for short duration vibrations began in the United States in 1959 where it was used an electro-hydraulic vibration table for tests (HSE 2001). In the 70s, backbone problems were associated with certain professions, indicating the need to understand the relationship between the exposure to occupational vibration and spinal problems. The first version of ISO 2631 was released in 1974. During the 80s, several studies provided information related to the magnitude of occupational vibration in agricultural tractors. However, the technology used was limited and restricted for some research centers that were able to perform tests for occupational vibration (Griffin, 1998; Mansfield, 2005). In 1982, ISO 2631 received amendments that defined the global weighted value of vibration by combining vibration from three axes x, y and z defining limits values and curves for comfort, fatigue and exposure to occupational vibration. In 1997, the revised version of ISO 2631 no longer brought the fixed and explicit limits for exposure to occupational vibration, being valid a graph relating acceleration x exposure time obtained by experimental observations, as well as vibration dose value calculations (VDV), and the estimated vibration dose value (eVDV). (Mansfield, 2005).

Nowadays, Directive 2002/44/EC European Parliament released in 2002 and more recently, Brazilian Regulatory Standard NR-15 (2014)-Annex 1 and 2, specifies numeric and fixed values (same values in both Regulatory Standards) for the vibration limits for both WBV and for HAV. These limits are specified for limit values of daily vibration exposure referred to 8 hours of exposure (aka ELV - Exposure Limit Value) as well as the action value of the daily exposure referred to 8 hours of exposure (aka EAV - Exposure Action Value).

1.2 Whole body vibrations, Localized vibrations and vibrations on Tractors

Griffin (1998) says that WBV are vibrations that are transmitted to the body as a whole, like feet, back and buttocks of a seated of stand human being. Exposure to whole body vibration can cause permanent physical damage or nervous system disorders (Piersol and Paez, 2010). Effects observed in groups exposed to severe vibration conditions were problems in the dorsal and lumbar region, gastrointestinal, reproductive system disorders in the visual system, problems with intervertebral disk degeneration in the spine (Saliba et al, 2002). For the vibrations to be felt as uncomfortable or unhealthy, it will depend on the level of acceleration, frequency and duration of exposure (Sell, 2002 Piersol and Paez, 2010 Griffin, 1998). Briefly, the problems related to vibrations in the human body, according to Sell (2002) and ISO 2631-1 (1997), are: lumbar problems and associated nerves, bone degeneration, hernias and impairment in performance; reduction on vision capability and perception in work situations; Gastrointestinal disorders, genital tract, muscle pain, cardiovascular diseases and modifications.

Localized vibrations are those that somehow can reach specific body parts like hands and arms. The main effects due to vibration in the hand-arm system can be vascular, neurologic, muscular and osteoarticular (Saliba et. al., 2002). Yadav and Tewari (1998) determined the human performance with respect to vibration, showing that the vibrations in the steering wheel can reduce operator comfort. According Sell (2002), the frequency of vibration is the decisive quantity for diseases in the hand-arm system, may cause thus wear on bones, joints and tendons of the hands and arms and consequently may occur arthrosis in the wrist, elbow and reach to the shoulder. Also according to Griffin (1998), continued exposure to occupational vibration arms and hands produces a set of symptoms known as Raynaud's syndrome and ulnar disease (pain caused by nerve compression). The first manifests itself in the form of vasospasms, incidental or intermittent. The phenomenon is the reduced blood flow characteristically attacking the hands, feet, and reduced form in the ears, tongue and nose. They are also associated with diseases such as osteoarthritis VMB, cinanose, carpal tunnel syndrome, Kienböck disease, tendinitis, hearing loss, vasoconstriction, impotence, sleep disorders, just to name a few (ISO 5349, 2001).

Mechanical vibrations occurring in tractors can be described by periodic and random components (Prasad et al., 1995). Periodic and regular vibrations are possible to predict, while the random are more difficult because it does not allow the prediction systematically (Santos Filho, 2002). According Arbets et. al. (1990) cited by Santos Filho (2002), the intensity of the vibration on agricultural tractors depends on the soil structure, tractor design (suspension seat, seat locations and cabin, tires), speed, technique of driving, among others. A study by Pessina (1986), cited by Berasategui (2000), and by Cvetanovic and Zlatkovic (2013) aimed to relate the vibrations on the seats of tractors during the transport phase, the travel speed and the coupling implements. The tractor went over a bumpy farm track and a standard for seat test, commonly referred to as ISO 5007 track. The used speeds in the experiment were 12, 15, 17 and 20 km/h. In the same study, it was concluded that the effective average acceleration level has increased with the speed and the vertical accelerations predominate in the operator's seat over the longitudinal and lateral ones. In addition, it was found that higher acceleration levels in the operator's seat generated by dragging implements over the hanging implements situation. Finally, the dominant frequency of vibration in the tractor was about 2.5 Hz. Santos Filho (2002) conducted a study in order to assess the levels of vertical vibration in the seat of a tractor using an automatic data acquisition system during plowing operation for different working speeds. Based on the obtained results, it is concluded that the acceleration levels in the seat were lower than the seat base levels for usual working speeds. The frequency range that presented the highest vertical vibration peaks was between 2 and 4 Hz; and the measured weighted acceleration values were above the limits set by ISO 2631-1 (1997) for a period of 8 hours. In addition, there was an increase in vibration levels with increasing speed of the tractor-implement system. A further reduction in vibration level may be obtained by introducing the suspension on the front and rear wheels, but this turns out to be a complicated and expensive system. Another way to reduce the level of vibration is the use of suspension cabins. This method is as expensive as adding suspension to the wheels, but have several other utilities, such as operator protection to the temperature variations, electronics packaging, insulation to vapors and gases produced by tractors, etc. (Prasad et al., 1995; Santos Filho, 2002).

1.3 Human exposure to vibration

The vibration consists of moving bodies equipped with the inherent mass and elasticity. The human body has natural vibration frequencies (Piersol and Paez, 2010). If an external frequency matches the natural frequency of the system, resonance occurs, which implies a movement amplification. The body because of the attenuation promoted by tissues and organs (Griffin, 1998) absorbs the vibration energy. The human body responds to vibrations in different ways. The sensitivity to longitudinal vibrations is different to lateral ones. In each direction, the sensitivity also varies with frequency, thus for a given frequency, tolerable acceleration is different depending on frequency content. Exposure to vibration transmitted to the human body, then, may be classified into two types, according to the body region affected: Whole-Body Vibration (WBV), those that are of low amplitude and mid frequency and are in the range of 1 to 80 Hz; Hand-Arm Vibration, that are located vibrations or hands and arms with frequencies that lie in the range 6.3 to 1250 Hz. In evaluated situations in this study, there is a simultaneous exposure to both types of vibration. The whole body, referring to the global movement of the vehicle and hand-arm system transmitted through the steering wheel. In order to standardize and evaluate these vibrations different standards were created. The most important are the international standards ISO (International Organization for Standardization) and the European standards. In Brazil, the current regulation is indicated by the Regulatory standard NR-15 (2014), which has the same threshold limits as the Directive 2002/44/EC but refers to the NHO-09(2013) and NH-10(2013) procedures for the measurements.

2. METHODS

The evaluation of vibration levels follows a methodology based on standards. The ISO 5349-1 (2001) and ISO 2631-1 (1997) should be used for the assessment of human exposure to vibration transmitted to the hand-arm system through the steering wheel of the agricultural vehicle and the transmitted whole body vibration to the seat and backrest.

The ISO 5349-1 (2001) standard HAV has the drawback of not specify categorical numerical values to characterize the limits and action thresholds for localized vibration, indicating only a percentage of the population that will experience problems associated with exposure. On the one hand, there is the caution in not specifying values that are not well established with cause-effect not completely reported. According Regazzi and Ximenes (2003), the rms value is the most important measure, since it takes into account both the chronology of the vibration wave and considers the value of the acceleration magnitude that is directly connected to the energy, therefore indicating the harmful potential. Moreover, the effects of vibration in relation to the human body is dependent on the vibration frequency content. As Griffin (1998) and Piersol and Paez (2010) say, the direction in which the human body is more sensitive is the vertical one. According to the author, 1 to 80 Hz is the range for the body's natural frequencies. Therefore, to correct this problem were developed weighting curves or compensation for different frequencies and axes. These curves are function of frequency and are used as a factor to assigns different weights to different frequency content. Aiming to qualify vibrations at frequencies in which the human body is more sensitive. This result in the so-called weighted rms acceleration, which is defined as a_w (m/s²). The a_w acceleration is given by Equation (1):

$$a_w = \sqrt{\int_{f_1}^{f_2} G_a(f) W_i^2 df} \tag{1}$$

where W_i is the weighting factor of the curve i in terms of frequency, G_a is the acceleration power spectrum and f_1 and f_2 are the integration limits (e.g., whole body 1-80Hz). The weighting frequency curves W_k and W_d are used in different cases to assess the vibration transmitted to the whole body and W_h is the weighting frequency curve used for the hand-arm vibration. According to ISO 2631-1 (1997), it is assumed that the effects of vibration are related to daily energy and two different exposure times are equivalent if $a_{w1}T_1^2 = a_{w2}T_2^2$. Other studies indicate the time dependence in the fourth root, but in this study, this relation will be used to generate values that are more conservative. The measurement of vibration should be done following a tri-axial coordinate system in which, for each of the x, y and z, resulting values of rms weighted frequency acceleration represented by a_{wx}, a_{wy}, and a_{wz}. Furthermore, k_i are multiplication factors used to allocate weights to the different coordinate axes. Table 1 shows the multiplication factors k used in the measurements with reference to ISO 2631-1 (1997) and ISO 5349-1 (2001). With these values as the sum of squares of the acceleration of each component multiplied by the specific multiplication factor the resultant total weighted accelerations is obtained $a_{v=}\sqrt{(k_x a_{wx})^2 + (k_y a_{wy})^2 + (k_z a_{wz})^2}$. In case there is a predominant axis of vibration, ISO indicates that the vector sum must be discarded and assuming the full acceleration as this value. For cases in which there is exposure to vibration in two or more periods for different durations and magnitudes of vibration, the total equivalent vibration $a_{v,e}$ calculates in accordance with $a_{v,e} = \sqrt{\sum a_{v,i}^2 T_i / \sum T_i}$ where $a_{v,i}$ is the total vibration for the T_i exposure time. It is worth mentioning that additional care must be taken concerning the orientation of the measuring axes and those defined by the measuring device to adhere the standard orientations.

Table 1. Multiplication factors used for vector composition of the resulting weighted acceleration.

	Weighting factors (health)								
	WBV (steering wheel)			HAV (seat)			HAV (seat back)		
Axis	x	y	z	x	y	z	x	y	z
Curve	W_h	W_h	W_h	W_d	W_d	W_k	W_d	W_d	W_k
k factor	1.0	1.0	1.0	1.4	1.4	1.0	1.4	1.4	1.0

2.1 Effects of vibration on health

Brazil has a new release of the Regulatory Standard No. 15 (2014) for vibration health assessment purposes. Standard indicates that the vibration exposure limits are strictly defined by equivalent levels like in the Directive 2002/44/CE (they present very similar level values). To evaluate the risks associated to the exposure, one should take into account the daily duration of exposure to particular vibration situation T_i (h), and the total time the individual is exposed to all vibration situations during a day $a_{v,e}$. The daily vibration exposure A(8) (m/s^2) is defined as $A(8) = a_v\sqrt{T/T_0}$ where a_v is the total equivalent vibration level (m/s²). For situations where there is more than one exposure period $A(8)$ is equal to $a_{v,e}$ and T_0 means a daily journey of 8h. This reference time T_0 is adopted in order to ease comparisons of daily exposures to vibration of different durations. The daily vibration exposure A(8) can be understood as a total value of acceleration (vibration) weighted by the frequency, equivalent to 8 hours of daily exposure. The Brazilian Regulatory Standard No. 15 defines A(8) as *aren* (*aceleração resultante de exposição normalizada*, in Portuguese).

ISO 2631-1 (1997) and Directive 2002/44/CE(2002) standard define lower thresholds related to a warning limits to vibration exposure that flags the vibration attained harmful levels to health and that this situation should be mitigated, like take some action to reduce vibration exposure of attenuate vibration in the source of vibration. The value termed as EAV indicates that for values above that limit, it is necessary to take measures aimed at reducing or eliminating this exposure. On the other hand, vibration values above ELV there is the need for immediate measured to cease vibration and exposure, since there are potential health risks. This recommendation in ISO 2631-1 (1997) is based primarily on shaded are in Fig. 2, in 4 to 8 h range.

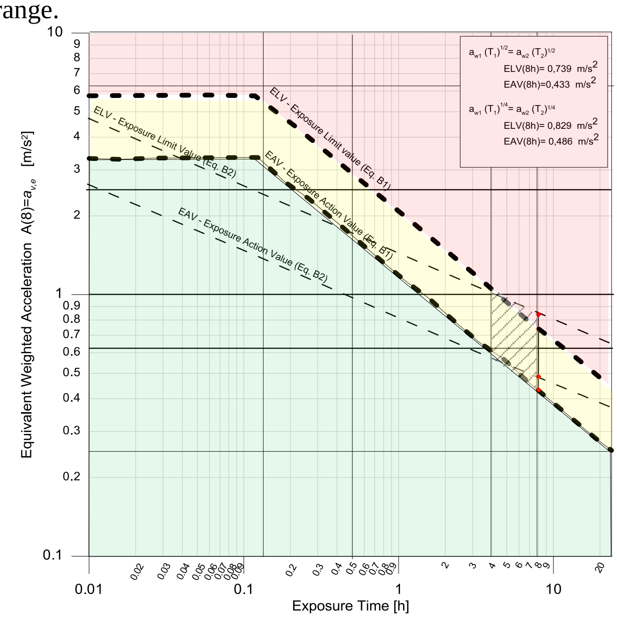


Figure 2. ISO 2631-1(1997) vibration exposure heath and action values, indicating safety zones (green), caution zones (yellow) and risk zones (red) (adapted from ISO 2631-1, 1997).

The Brazilian Regulatory Standard NR-15 (2014) for HAV sets EAV of 2.5 m/s^2 and ELV of 5,0 m/s^2. For the WBV the Brazilian Regulatory Standard (NR-15, 2014) sets for EAV 0.5 m/s^2 and for ELV 1.1 m/s^2. Those values are practically the same to those defined in Directive 2002/44/EC, 2002 (for HAV, EAV of 2.5 m/s^2 and ELV of 5.0 m/s^2 and for WBV, EAV 0,5 m/s^2 and for ELV 1.15 m/s^2). ISO 5349-1 (2001) for HAV sets a graph that indicates the limit for a 10% of prevalence of vibration-induced white finger disorder in a group of exposed persons. For an equivalent 8h of exposure, this value for HAV is A(8) =3.7 m/s^2 and it is not clear if this is an action value of a limit value. In the same way, ISO 2631-1(1997) WBV limit values can be inferred from Figure 2 for a 8h of exposure as EAV of 0.43 m/s^2 and ELV of 0.74 m/s^2. The daily vibration exposure action values (EAV) and daily exposure limit value (ELV) used are shown in Table 2.

To assess the vibration level in the agricultural vehicle it was used the portable vibration analyzer QUEST VI-400Pro, S/N 12430. This vibration analyzer capable of measuring up to four input channels simultaneously, each including 1/1 or 1/3-octave real-time band. Three channels are typically used for measurements in the three coordinate axes. Connected to the handheld vibration analyzer are used accelerometers, which are placed in locations that are experiencing the vibration. Accelerometer is connected directly to the vibration meter, which indicates the level of the weighted rms acceleration to the measured measurement time. For the vibrations in the backrest and the seat it is used the standardized a seat-pad. The measurements was performed with a tri-axial accelerometer 070-030, S/N 646, with nominal sensitivity of 100.3 mV/g in each axes. For the steering wheel vibration measurements it was used a tri-axial piezoelectric accelerometer Dytran, model 3023A2, S/N 4147 with sensitivity of 10 mV/g for each axis. The travel speed of the tractor was measured with a commercial GPS, ROADSTAR RS-600 model.

Table 2. EAV and ELV reference values used in the assessments for 8h exposure.

	Reference Values (m/s²)		Vibration Dose Value ($m/s^{1.75}$)	
	EAV	ELV	EAV	ELV
ISO 2631-1(1997)* and ISO 5349 (2002)				
HAV	-	3.7	-	-
WBV	0.43	0.74	-	-
Directive 2002/44/EC (2002)				
HAV	2.50	5.00	-	-
WBV	0.50	1.15	9.1	21
Regulatory Standard NR-15(2014)				
HAV	2.50	5.00	-	-
WBV	0.50	1.10	9.1	21

* (By interpolation of the curves for 8h)

Measurements were performed on a Massey Ferguson 4275 tractor with agricultural implement MF 407 L45 also with the same brand, both model 2011 (Figure 3). The tractor had radiator and fluid containers lubrication under normal conditions. The fuel tank was at half of capacity. The used tires were of standard size for the tractor, according to manufacturer's specification with pressure in the front tires of 16 psi (110 MPa) and at rear tires with 18 psi (124 MPa). A driver operator with a mass of 78 kg was used in the measurements. The tractor-implement system was tested under harvesting field conditions in a soybean planting area and without obstacles, in the municipality of Chapada, RS, Brazil. For the evaluation of vibration in asphalt paving and unpaved road, commonly called "dirt road", it was used the tractor without the agricultural implement. Figure 3 shows the tractor as well as the pavements in the evaluated conditions.

The used speeds in the test were stipulated based on the tractor activity as usual for harvesting, plowing and planting. For the planting operation was used to speed of 7 km/h, which is the speed required for direct planting of soybean seed. The other speeds were used speed ranges commonly developed in real situations. The actual speed was determined by a commercial GPS and engine speed indicated by the tractor’s display panel. The situations were: (a) paved road 14 km/h speed of 1600 rpm and 5th. gear, (b) unpaved road, 12 km/h speed of 1500 rpm (c) planting operation to 7km/h, speed 2200 rpm and 3rd. gear.

(a) 

(b) 

Figure 3. (a) Tractor and used agricultural implement, (b) paved road, (c) unpaved road.

2.2 Agricultural Vehicle instrumentation

It was used two types of accelerometers for the vibration measurements. An accelerometer attached to the steering wheel to determine the vibration level in the hand-arm system, according to ISO 5349-1(2001) and NR-15 (2014). Another seat-pad type accelerometer for measurements on the seat, the base of the seat and backrest for WBV level. Each measurement was performed separately for each measurement point, last about 60 seconds in each condition, and rated location because it was judged sufficient and representative of the evaluated vibration condition. The accelerometers were placed in accordance to the ISO standards, having been aligned with respect to the orthogonal axes.

3. RESULTS

3.1 Evaluation of vibration levels

Figure 4 shows the values of vibration levels in the seat base, seat, backrest and steering wheel, respectively, obtained experimentally. Each graph shows the measurements for each situation in which the tractor has been reported in operation. According to the graphs, one can see the magnitude of acceleration as a function of the measurement site and the performed operations. Three graphics are related to the tests carried out respectively in the asphalt, unpaved road and planting operation. Each graph is evaluated separately for each type of operation, having on the x-axis the location where the accelerometer is applied, and the y-axis the total weighted acceleration. Evaluating separately the measurements in each situation, it was found that regardless of the type of test, the magnitude of HAV vibration in the steering wheel was superior to the others, exceeding in all trials 5 m/s^2. It should be noted that this vibration could be related mainly to the vibration transmitted from the engine to the steering wheel, because even on asphalt, which is a pavement far less plane, the acceleration level is has high level. It is assumed that the reduced vibration level in the unpaved road condition and planting situation is because part of the tractor vibration is absorbed by the ground (plowed land) less stiff than in the paved situation, where the vibration is reflected and not absorbed. The fact that the wheel has large diameter and tractor has no suspension system, also contributes to this high level of HAV. It can be observed in the tests that the vibration level in the WBV seat is reduced in relation to the seat base, which is a result of the suspension system comprising springs in the present foam and seat. However, the unpaved road was not verified this result. Comparing the experimental results (Figure 4), one ca observe the difference in magnitude in vibration of the measurement points related to different types of pavements.

(a) (b) (c)

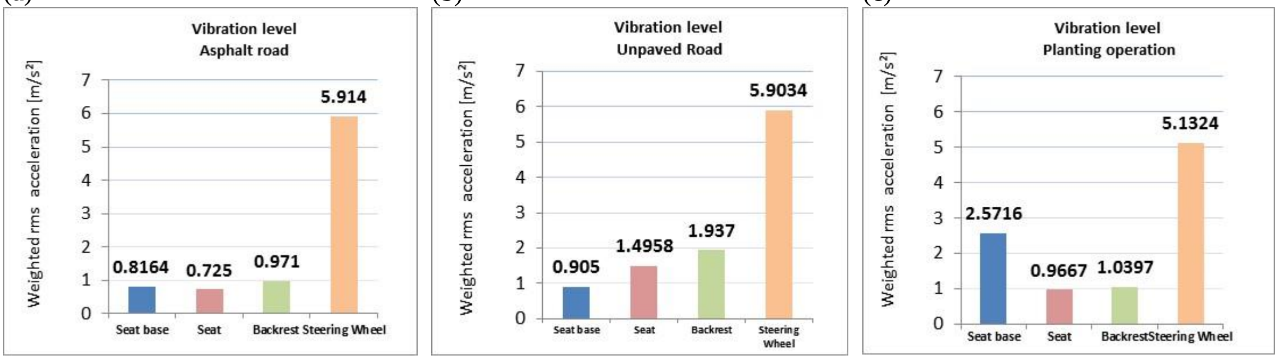


Figure 4. Analysis of vibration levels at different tractor locations and pavement (a) asphalt, (b) non-paved road, (c) planting operation.

The high VCI acceleration values in planting operation are attributed to the movement of the tractor on the plowed surface and pulled implement, which gave an overall weighted acceleration value of 2.571 m/s^2, which is a value very close to the evaluated levels of vertical vibration on tractor's seat by Santos Filho (2002). In his work, it was found, for tractor in third gear, an overall weighted acceleration of 2.638 m/s^2 (with the pulled implement and speed of approximately 7 km/h. The acceleration levels on unpaved road were also high due to the road be more compacted, with irregularities, holes and stones, showing that the tires were not enough to dampen the produced vibrations. Finally, in general, the WBV level in the asphalt presented less magnitude, especially because the pavement was less rough and smooth.

3.2 Evaluation of vibration levels on health

Analyzing the data related to vibration exposure (WBV), one can note that the values, in all situations and road profiles (except for asphalt and seat), are beyond the ELV from ISO-2631-1 (1997) point of view. However, it is below the ELV according to Directive 2002/44/EC and NR-15 except for planting operation and seat base and unpaved road, seat and backrest as shown in Table 2. In a safety assessment, using ISO 2631-1(1997) limits, it can be interpreted as acceleration values that are harmful to the operator's health. Related to HAV, in any situation, the measured acceleration value exceed the ELV.

It was simulated working journeys of 4, 6 and 8 hours, using different combinations measured road profiles. Table 3 shows three work routines that differ in exposure on the situation of planting and working day journey. The Routine A presents a lighter work situation, 3 hours of work with the tractor in planting operation, and another hour commuting (0.5 hours on asphalt and 0.5 hours on unpaved road). The routines B and C have similar characteristics to the routine A, but with increased exposure in the planting operation.

Table 3. Daily routines for the tractor usage.

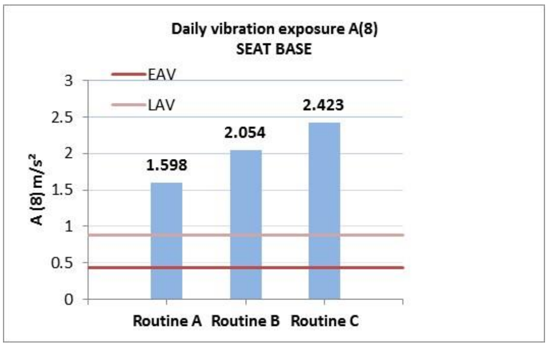
	Unpaved Road (12 km/h)	Asphalt (14 km/h)	Planting (7 km/h)	Daily hours
Routine A	0,5 h	0,5 h	3,0 h	4,0 h
Routine B	0,5 h	0,5 h	5,0 h	6,0 h
Routine C	0,5 h	0,5 h	7,0 h	8,0 h

Thus, one can compare the influence on the situation in which the tractor is effectively used to refer to the daily exposure to vibration. In all routines it was not simulated the situation representing the engine running at idle because this is not a situation that normally occurs. The total equivalent vibration was calculated, and the daily vibration exposure

A(8) evaluated. Figure 5 and Figure 6 provides four graphs, one for each measured measurement, comparing the daily vibration exposure A(8), for each routine. The horizontal lines of the graphs represent the exposure action value (EAV) and the exposure limit value (ELV) in accordance with the values in Table 2 for the NR-15 (2014). In the horizontal axis, each bar represents a routine, and the vertical axis, the corresponding values of daily vibration exposure A(8).

From the graphs, one can deduce that in all measurements, in all routines, EAV defined by the ISO 2631 standard has been exceeded and for the routines of longer exposure, these values exceeded the ELV. Thus, for operator safety, there is a need for measures aimed at reducing or eliminating this exposure. For vibration measurements at the seat base, all routines proposals presented values above the exposure limit value ELV, i.e., the operator is subjected to unhealthy vibration levels. For the measurements on the seat, the vibration levels were also high, whereas for the routine C, the exposure was above the ELV. In the backrest measurements, in routines B and C, the vibration values were above the ELVs. A similar situation occurred for measurements on the wheel in which the routine A and B resulted in values above the EAV having routine C values above ELV. Considering a daily 8-hour exposure (Routine C), the measurements exceeded the limit levels in all measurement points, thereby exposing the operator to potentially harmful levels. With these values of daily exposure to vibration, it is necessary to take immediate action to mitigate the vibration level, since this situation may generate health problems to the driver (ISO 2631-1, 1997).

(a)



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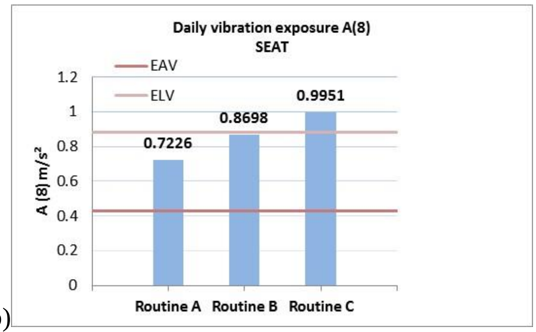
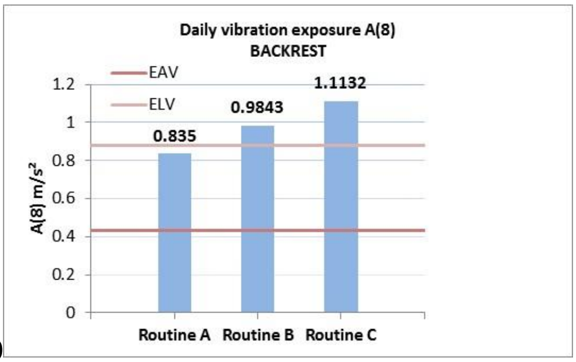


Figure 5. Daily exposure to vibration A(8) (a) seat base and (b) tractor seat and usage routines.

It is observed that the calculated values of total weighted acceleration in WBV are above ISO 2631 (1997) limits, even for an exposure of 4 hours.

(a)



(b)

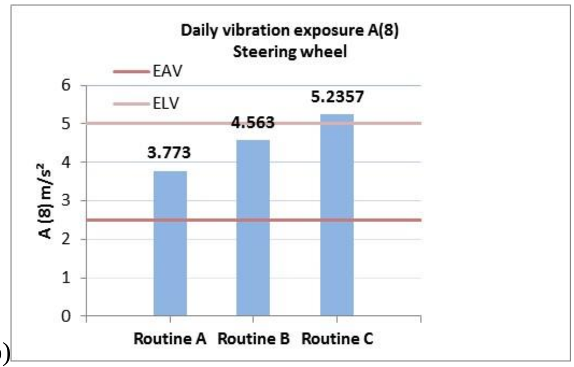


Figure 6. Daily exposure to vibration A(8) of (a) backrest and (b) tractor steering wheel and usage routines.

The critical measurement is at the seat base, with very high values of total weighted acceleration, especially in the planting operation, which is a common situation, thereby exposing the driver to high daily vibration levels.

4. FINAL REMARKS

According to the presented results, it was found that the acceleration levels were high in most of situations. For instance, the lowest total weighted acceleration was 0,725 m/s^2 at the tractor seat on the asphalt situation; and a value of 5.914 m/s^2 at the steering wheel, also on the same pavement. As similar studies on the vibration on agricultural tractors, on different terrain and operating conditions, acceleration levels on the seat were found lower than the seat base for two of the three conditions tested, which at least shows the seat cushion efficiency.

The overall weighted acceleration values on the steering wheel were above 5 m/s^2 in all assessments, noting that the vibration on the steering wheel may be generated by engine vibration in the direction in addition to the pavement, Even in the asphalt situation, which is considered the most regular pavement, the vibration reached high levels presumably by a vibration reflection effect generated by the tractor (with no payload) and the stiff pavement, which instigates further study on this situation. In fact, driving on asphalt and unloaded, noticeably created more vibration in the tractor. For health assessment, all work routines simulated resulted values above the EAV, some values even exceeding the daily exposure limit value (ELV). The vibrations occurring in the seat base were worrying, because it was found values far above the limits set by the standards, even in shorter work routine. In other measuring points, acceleration levels exceeded the daily exposure action value (EAV) for all simulated routines. For the routines requiring 7 hours of work in the field, all measurements exceeded the limit of daily exposure to vibration (ELV). Thus, it requires actions aimed at reducing or eliminating this exposure. Thus, it is suggested that a cabin with suspension system (cushions) in the agricultural tractor can reduce the level of vibration that the driver is exposed during the routine work. In addition, applying a suspension system between the base of the seat and the seat will also promote the reduction of vibration transmitted to the operator. The improvement of the actual seat suspension system may considerably bring the acceleration levels below the limits. Another way to reduce this exposure to vibration is to create work scales with more drivers, thus diluting the daily exposure to vibration, so that it can be avoiding passing the threshold limits for a particular driver. In view of the results, this study suggests an urgent investigation like this one performed in this study to other types of agricultural operations, such as harvesting, tillage, spraying, etc.

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6. RESPONSIBILITY NOTICE

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